Deuterium retention studies in Alcator C-Mod

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PFC divertor meeting

UCSD

Feb. 2006

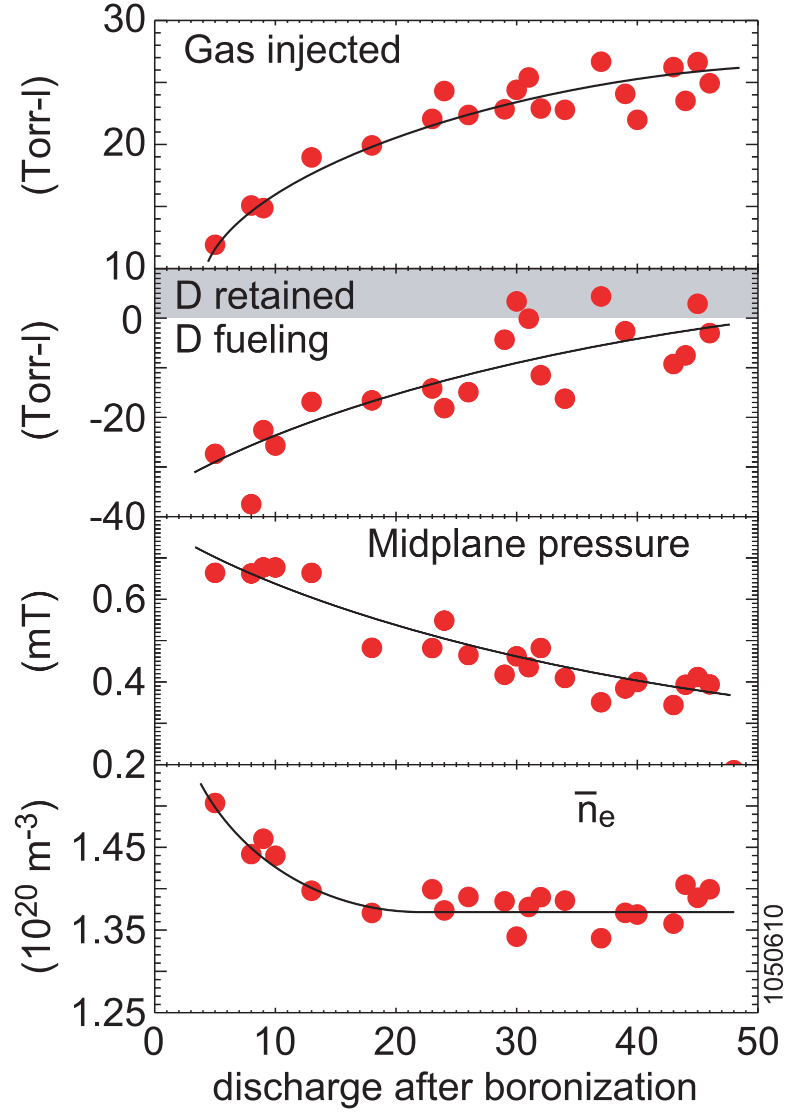
Outline

- Global D retention & recovery.

- Boron and deuterium deposition in tile gaps.

Recycling and retention studies in parallel with C-Mod boronization study

- Very accurate gas balance in C-Mod
  - ➢ External pumping closed through discharge + 5 minutes
- The recycling effects of BZN are mostly worn off after 50 shots
  - ➢ PFC surfaces shift from dominant fueling to pumping
- **After initial BZN effect or after in-vessel boron cleaning PFC surfaces net retain fuel.**

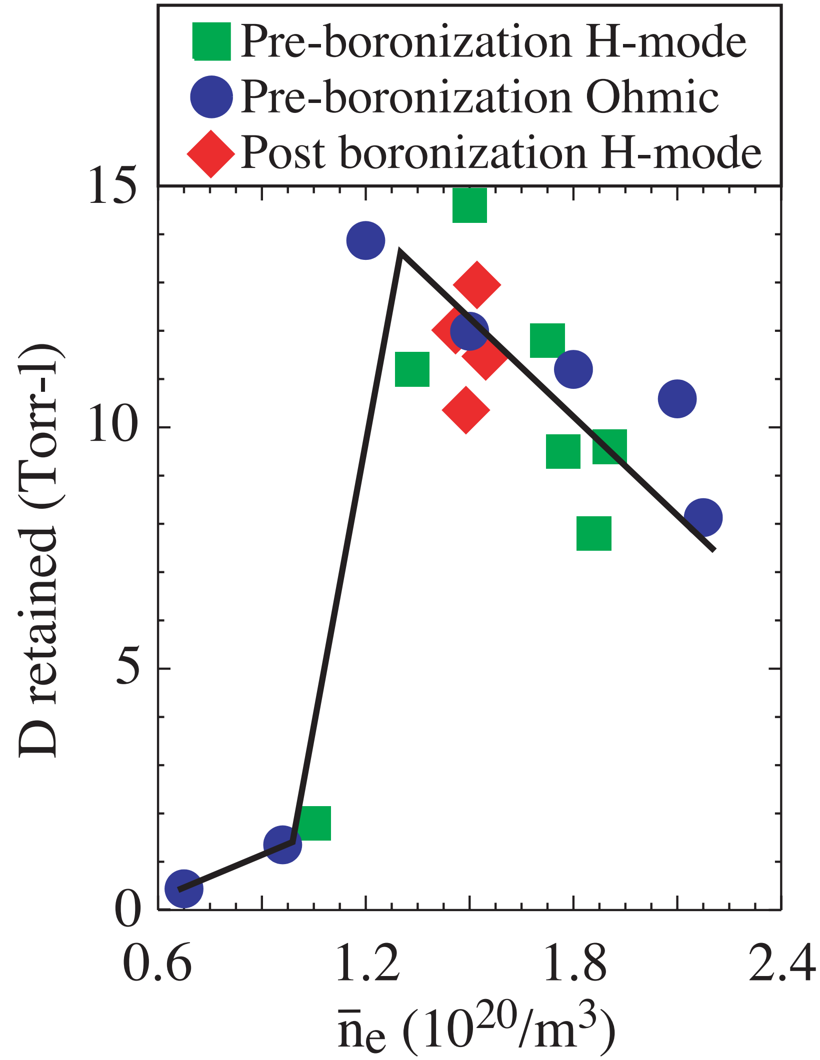


Both cleaned and boronized Mo surfaces can retain large amounts of Deuterium fuel

- **Pre-boronization**:
  In-vessel cleaning of all Boron coatings.
  - ~10-20% B near surface (< 1 micron)

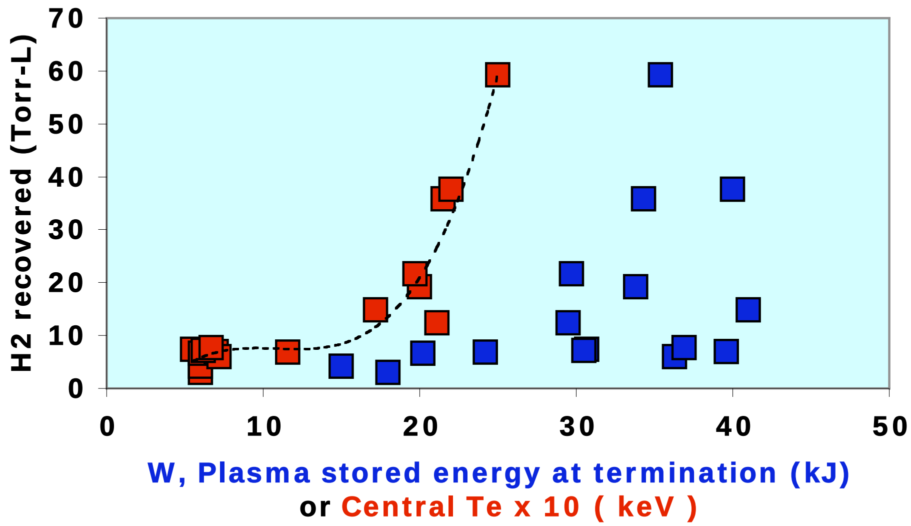
- D retained ~ 25- 50% of that gas injected for the discharge, essentially independent of boron coatings.
  - D retention process uncertain; not expected for Mo; surface impurities?
  - **Time-integrated retention lower due to natural and planned disruptions, etc.**

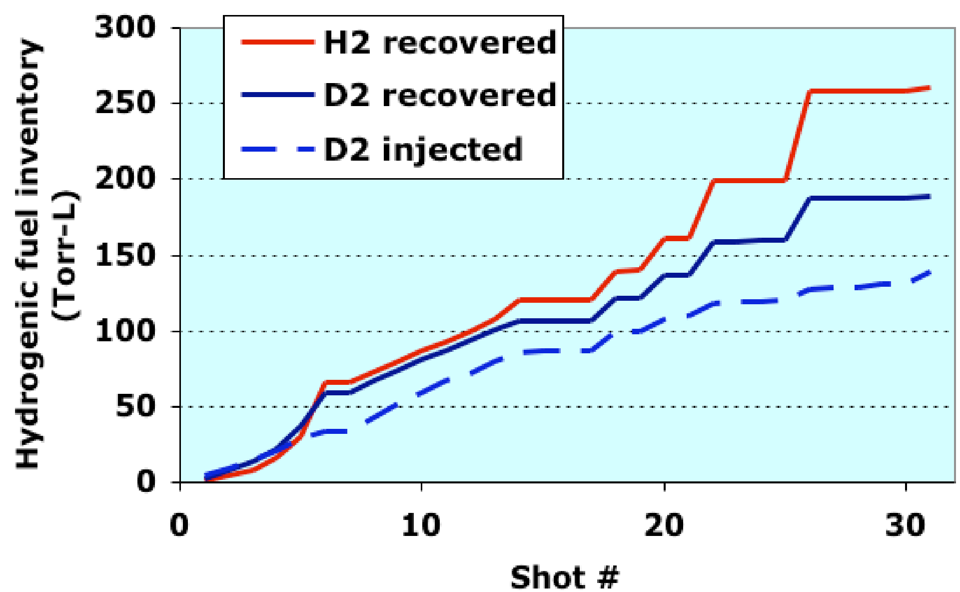
- After initial threshold, wall retention has weak dependence on plasma density.



Planned disruptions prove effective at *recovering* the D from the wall through forced H_2 / D_2 desorption by surface heating

H/D recovery experiment with planned disruptions



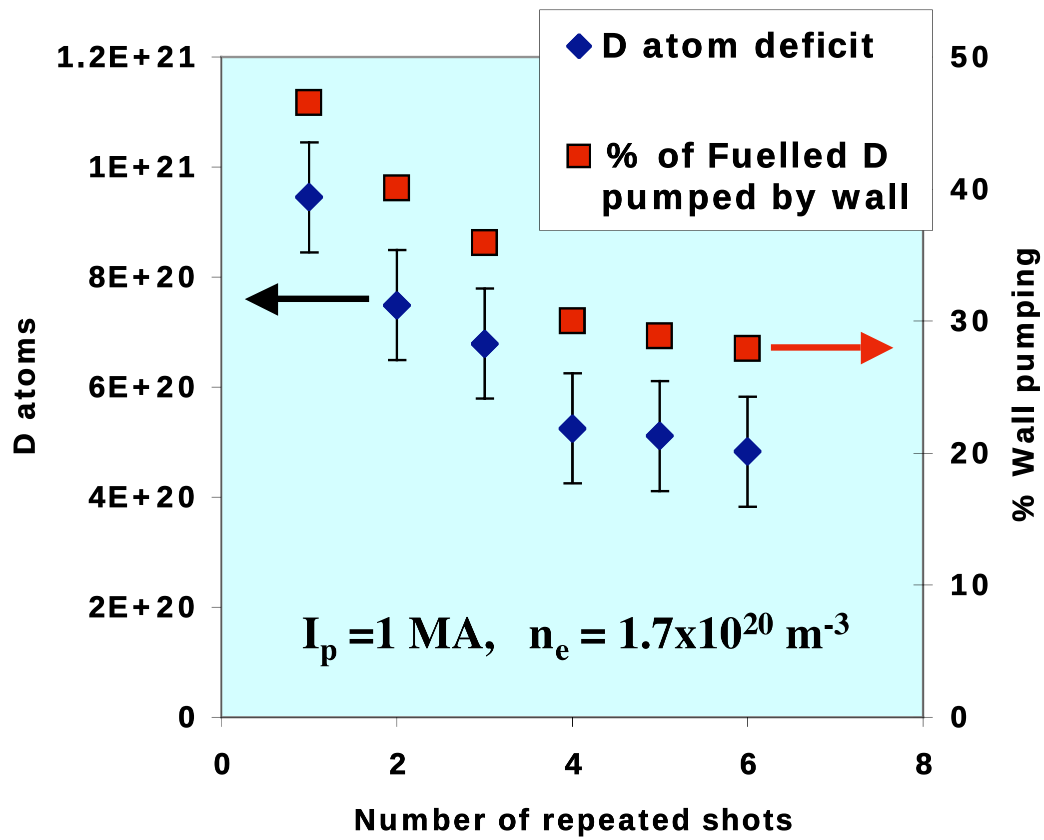


Found expected energy density threshold for H_2/D_2 recovery:
$\Delta T_{max} \sim W_{th} / A_{wetted}$

Recovered ~30% H_2 in single operation day.
H/D reduced ~35%
Wall H/D depleted over day!

Further retention studies with cleaned Mo walls. Repeated discharges show D retention evolution, but no sign of saturation.

- Retention measurements after May 05 clouded by titanium dust in vessel.
- Subsequent in-vessel cleaning allowed for **retention experiments with Mo dominated walls.**
- Repeat discharges with ***avoidance*** of disruptions in current rampdown, finds steady-state ~30% retention.

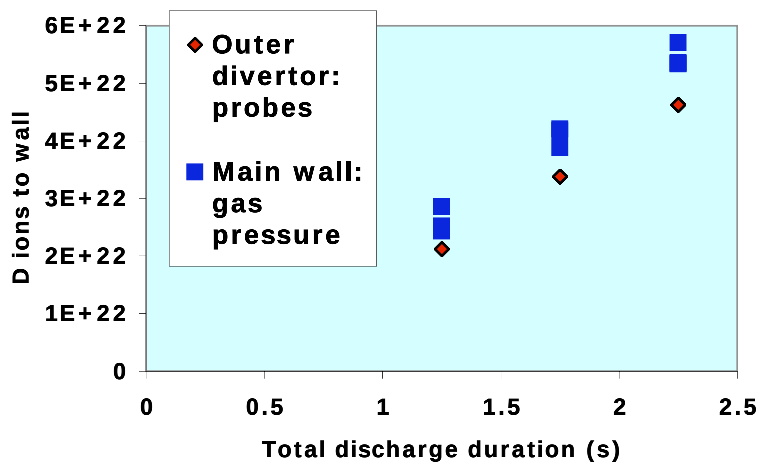


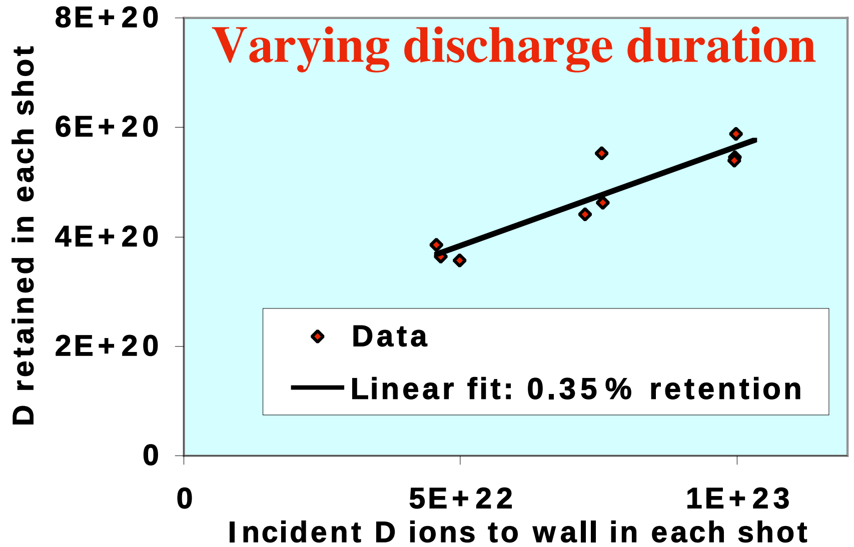
Implications?

- Fuelling: ~ 5 x N_D in plasma
- ITER: 100 g Tritium / pulse

D retention seems to scale as total ion fluence to walls:

D retained / D ion to wall ~ 0.3 - 0.5%





- Discharge duration was varied to change the total ion bombardment.
- Probes and pressures used to measure total ions to wall
  - ~10^{23} ions / shot ~ 100x D_2 fuelling.
  - **$A_{divertor}$ ~ 0.3 m^2**
  - **$A_{main-wall}$ ~ 1 - 5 m^2 ??**

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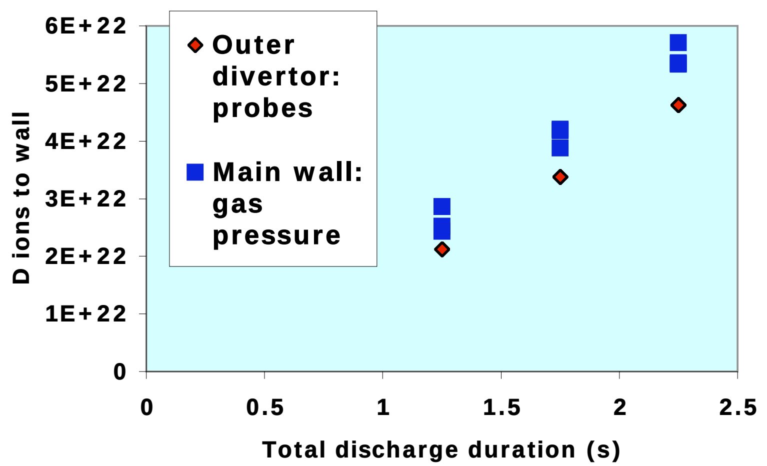

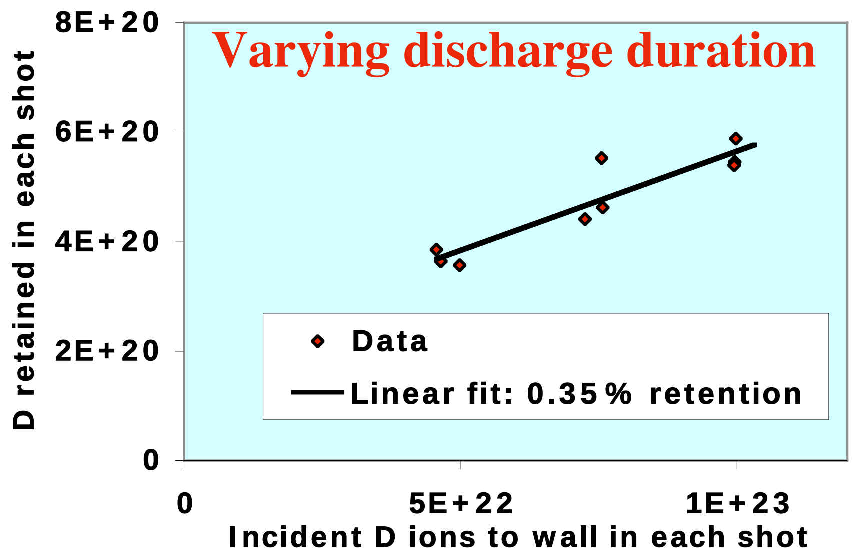

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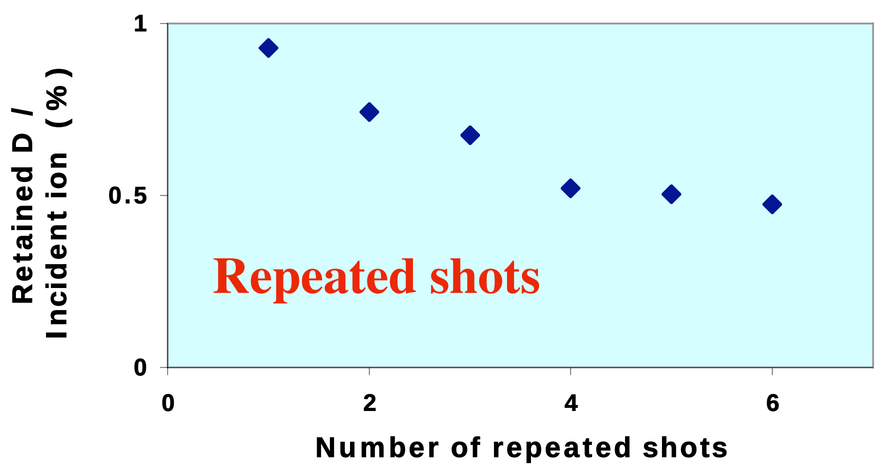


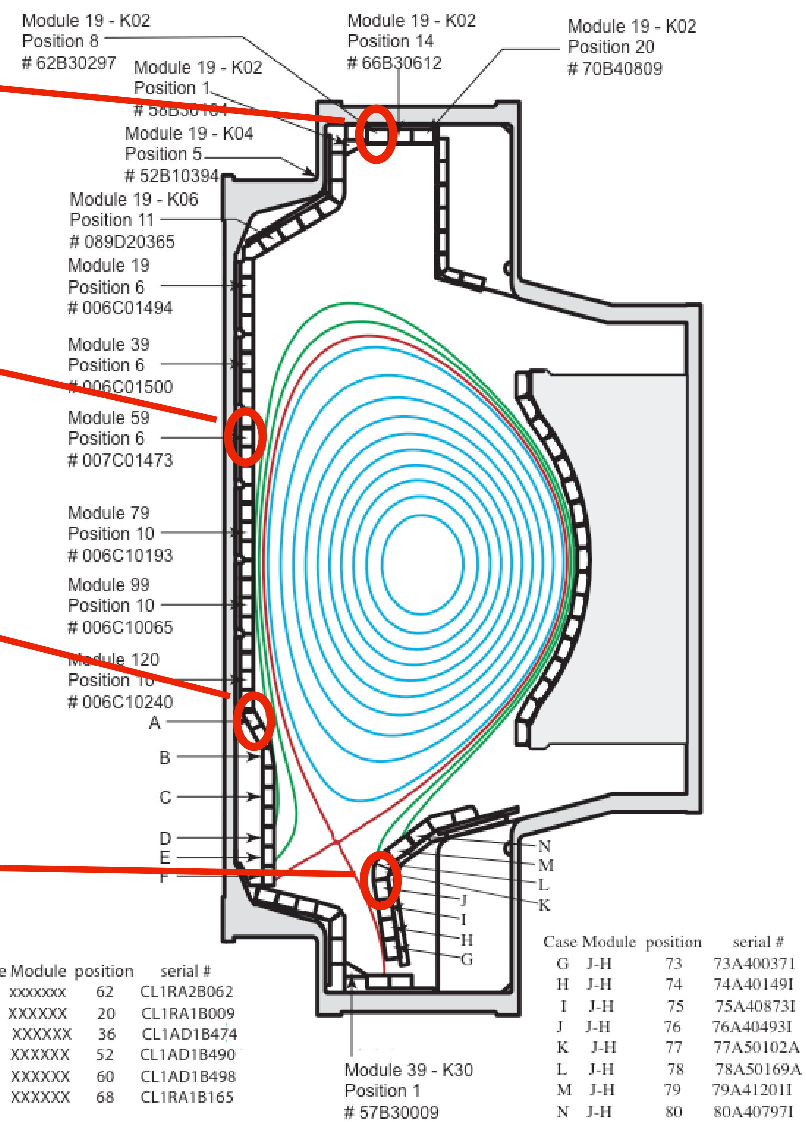
Outline

- Global D retention & recovery.

- Boron and deuterium retention in tile gaps.

Four poloidal locations examined for tile gap deposition

- **Upper divertor**
  - ➢ Very far from separatrix in standard divertor configuration
- **Inner wall**
  - ➢ Plasma startup on inner wall.
  - ➢ Tiles exposed for ~7 years
- **Inner divertor**
  - ➢ Nose at entrance to inner divertor
  - ➢ Front-surfaces: some boron deposition caused by discharge plasma exposure
- **Outer divertor**
  - ➢ High recycling and power flux.
  - ➢ "Cleaned" plasma-facing side

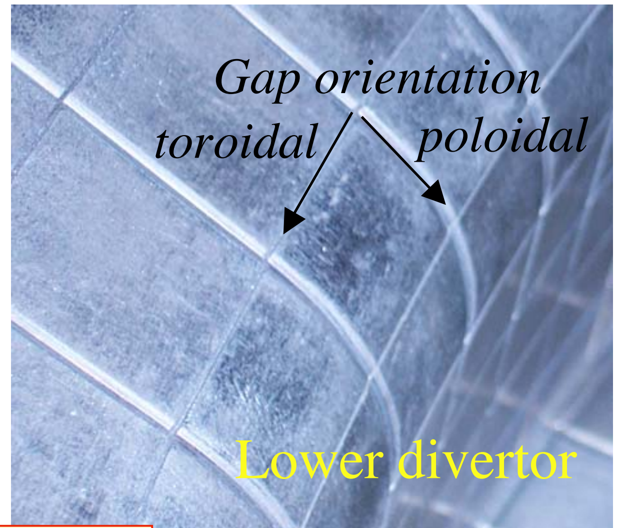


Case	Module	position	serial #
A	xxxxxxx	62	CL1RA2B062
B	XXXXXX	20	CL1RA1B009
C	XXXXXX	36	CL1AD1B474
D	XXXXXX	52	CL1AD1B490
E	XXXXXX	60	CL1AD1B498
F	XXXXXX	68	CL1RA1B165

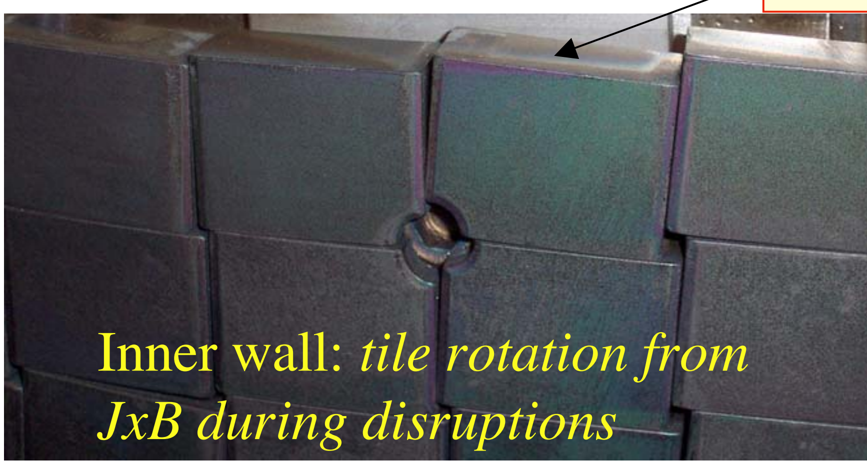
Case	Module	position	serial #
G	J-H	73	73A400371
H	J-H	74	74A40149I
I	J-H	75	75A40873I
J	J-H	76	76A40493I
K	J-H	77	77A50102A
L	J-H	78	78A50169A
M	J-H	79	79A41201I
N	J-H	80	80A40797I

Tile gaps in C-Mod

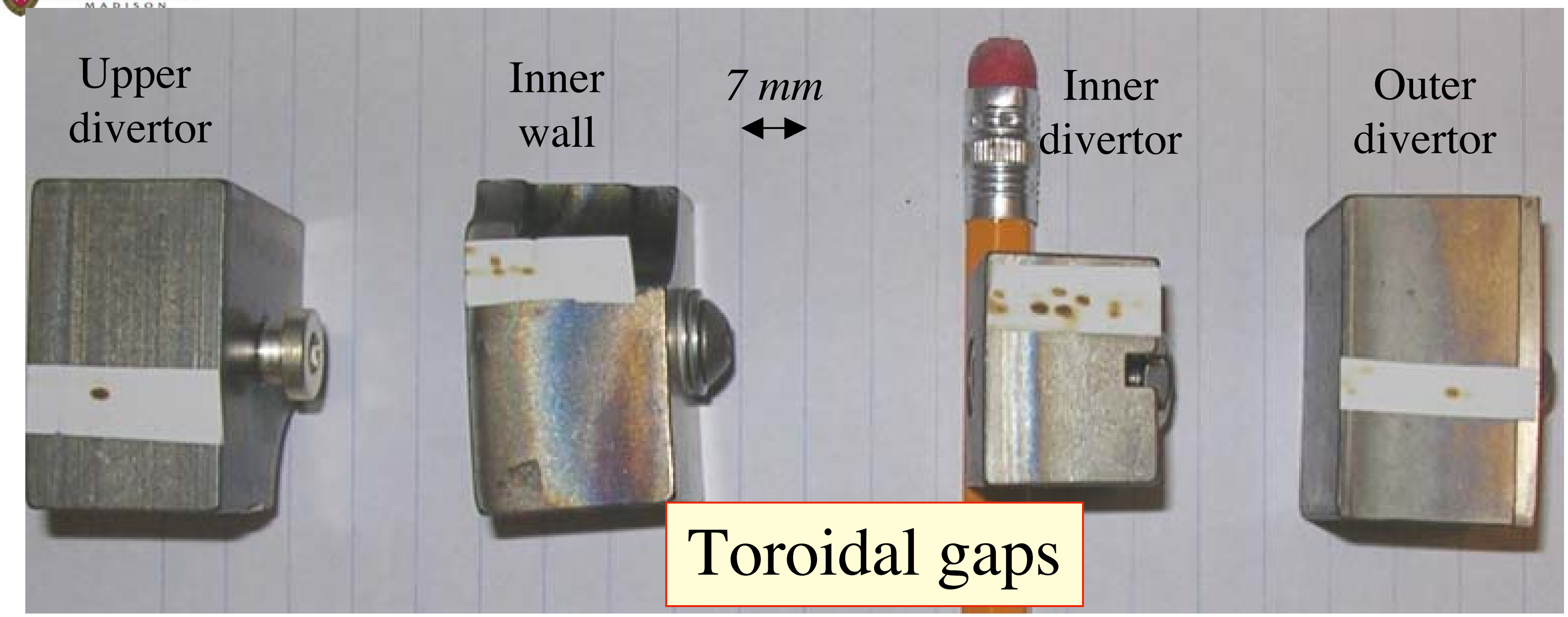
- Typical tile size **~ 25 x 35 mm**.
- Nominal gap distance: **0.5 mm**.
- Gap surface coverage **~ 2-4%**



Deposition in gaps

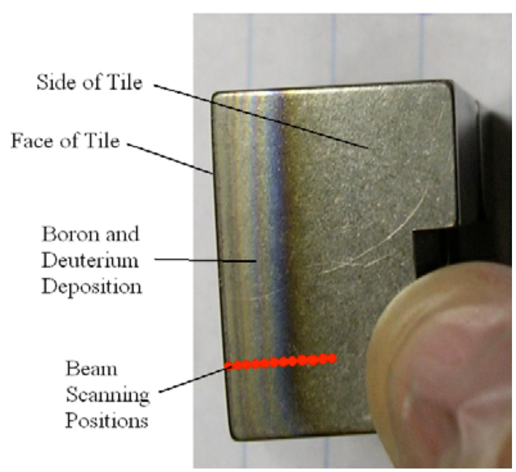


Analyzed tiles chosen with toroidal/poloidal uniform deposition profiles --> improved accuracy for gap "inventory"



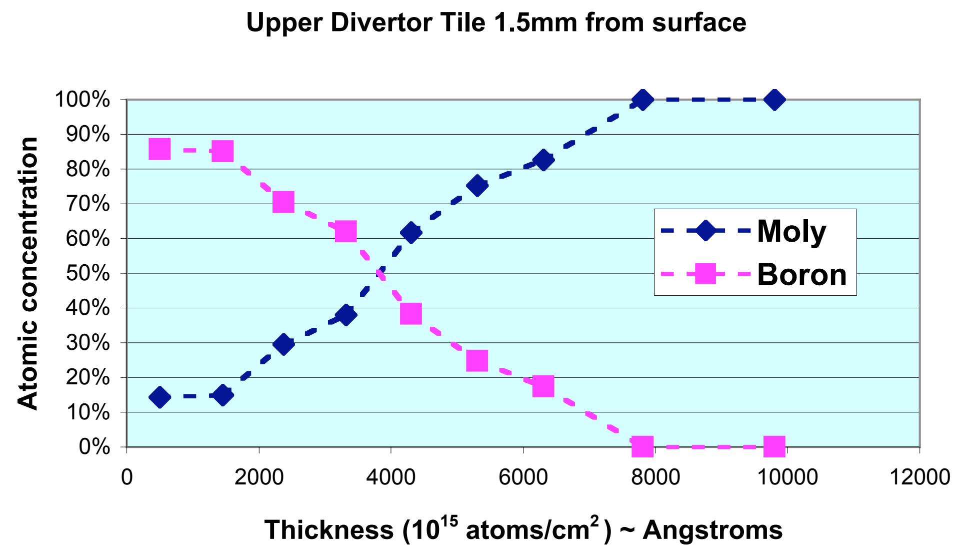
- Boron interference patterns evident for film depths ~ 30 - 500 nm.

C-Mod Tile



- **Ion beam analysis at UW-Madison**
  - RBS (B/Mo)
  - NRA (B/D)
- ~ 0.5 mm spot size

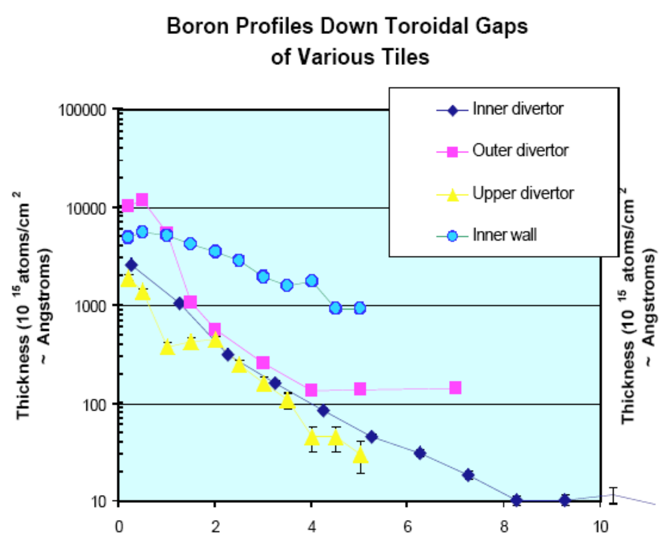
Deuterium is codeposited in tile-gaps with low-Z boron

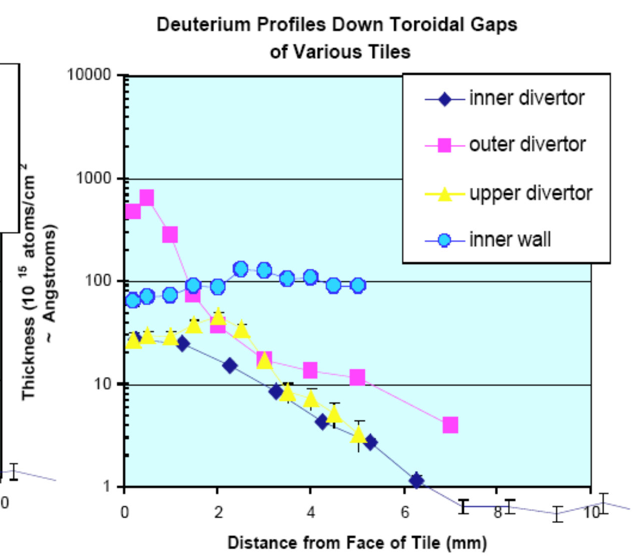


- Like front surfaces, Boron + Mo appear to inter-diffuse
  - ➢ Surface roughness effect?

- Deuterium surface concentration **correlated** to Boron deposition
  i.e. **Codeposition**.

- Unlike plasma-facing surfaces, no Deuterium retention in ~pure Mo deep down gap.





Boronizations play an important role in tile-gap deposition on C-Mod

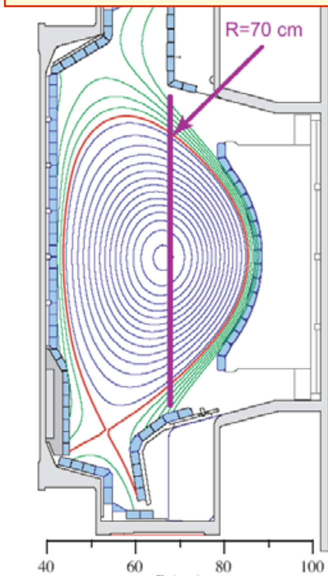
- Boronization provides the “initial” low-Z boron, some of which is eventually found down tile gaps.
  - ➢ Approx. 5 microns cumulative B layers on tile surfaces over 5-7 years.

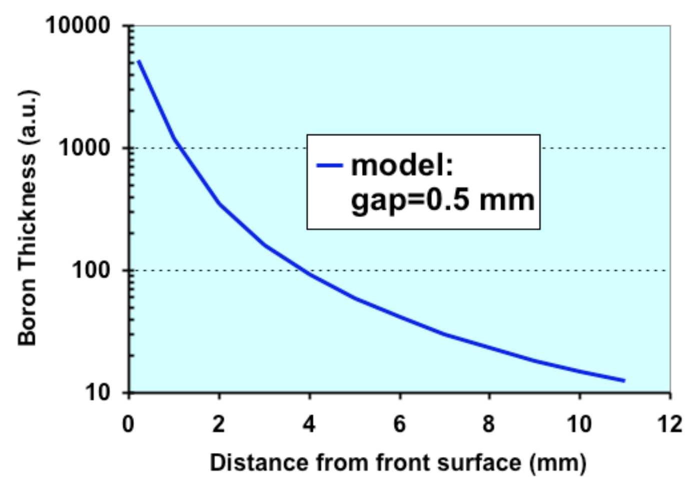
- Deuterated diborane in Electron Cyclotron (EC) discharge with static $B_T \sim 0.05$ T and $T_{wall} \sim 120$ C
  - ➢ B_T scanned to sweep EC resonance across R.
  - ➢ Typical ECD plasma: $T \sim 10$ eV, $n \sim 10^{17}$ m^{-3}
  - ➢ Source of deuterium for codeposition in gaps.

- Boron: ρ_i **~ 20 mm >> δ_{gap}**

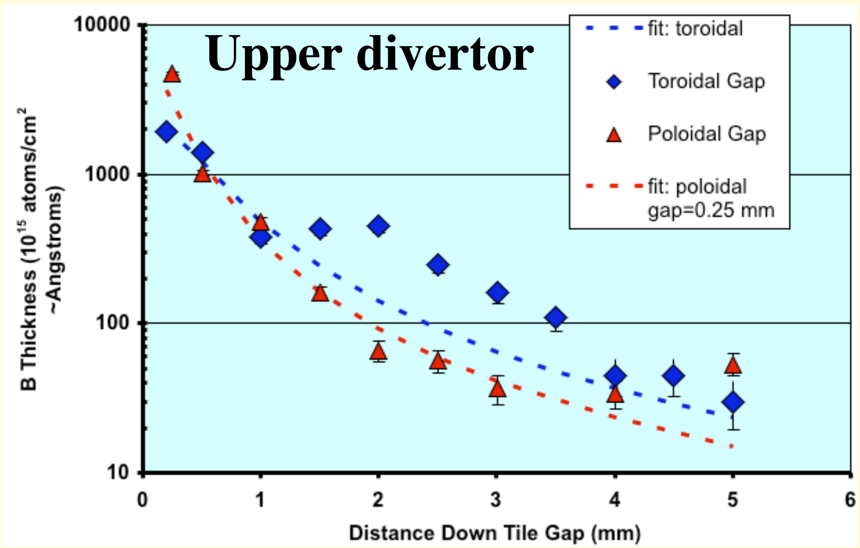
- **Tile gap deposition during boronizations must come from neutral boron deposition caused by dissociation of diborane in ECD.**
  - ➢ Geometric model constructed for expected boron profile down gap.

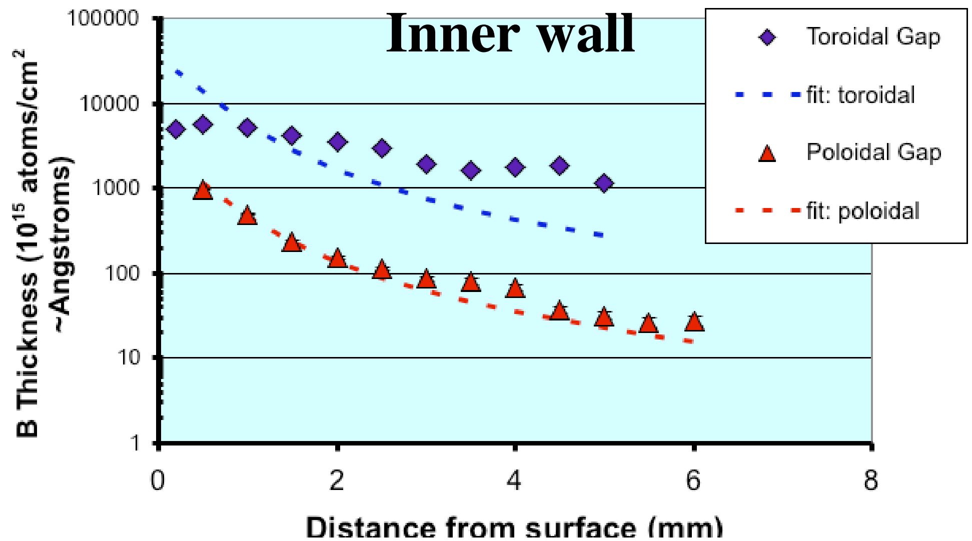
EC resonance swept With B_T



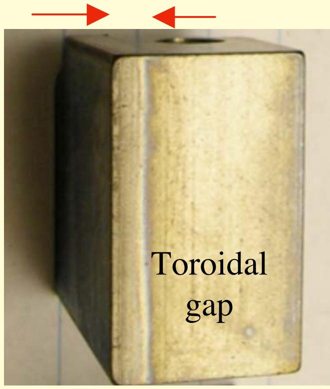


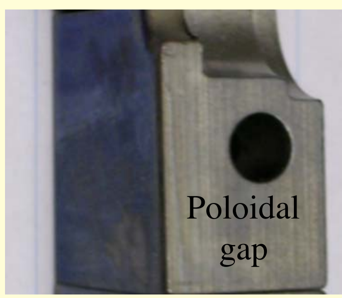
Boron gap deposition: Main-wall tiles





5 mm to last fringe (~ 50 Angstroms)





- Mostly dominated by BZN neutral deposition?

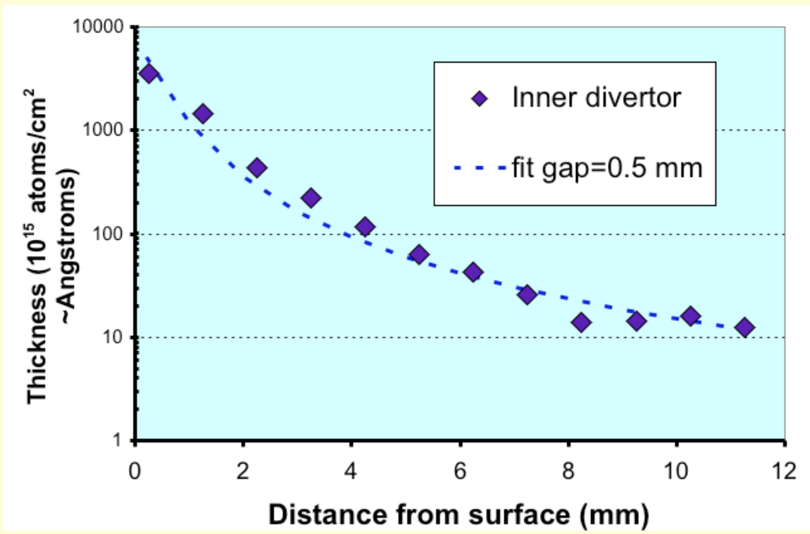
- Poloidal gap consistent with BZN
- Toroidal gap **inconsistent** with BZN
  --> ionic deposition (ρ_i small enough)?

Boron gap deposition: Divertor tiles

THE UNIVERSITY of WISCONSIN MADISON

Alcator C-Mod

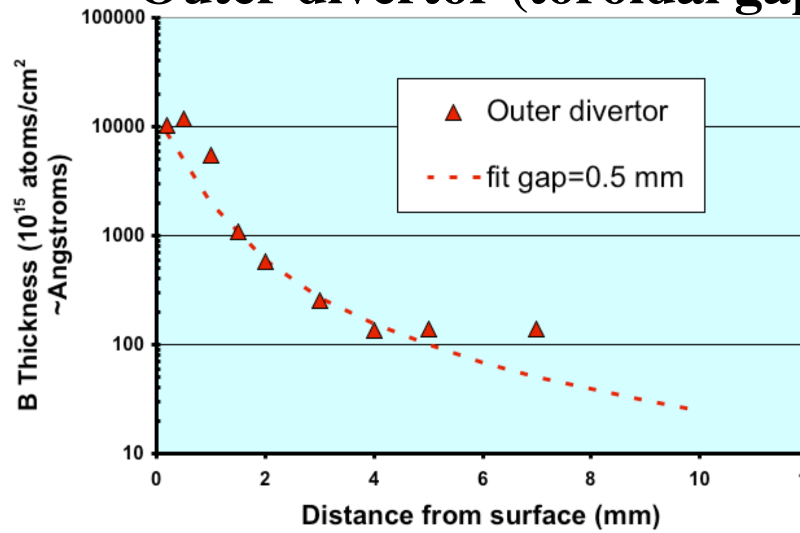
Inner divertor (toroidal gap)

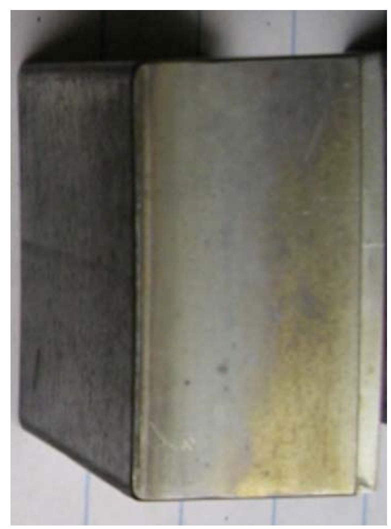


5 mm

- Consistent with BZN despite high rate of deposition on front surface.
- Poloidal-running gap identical

Outer divertor (toroidal gap)

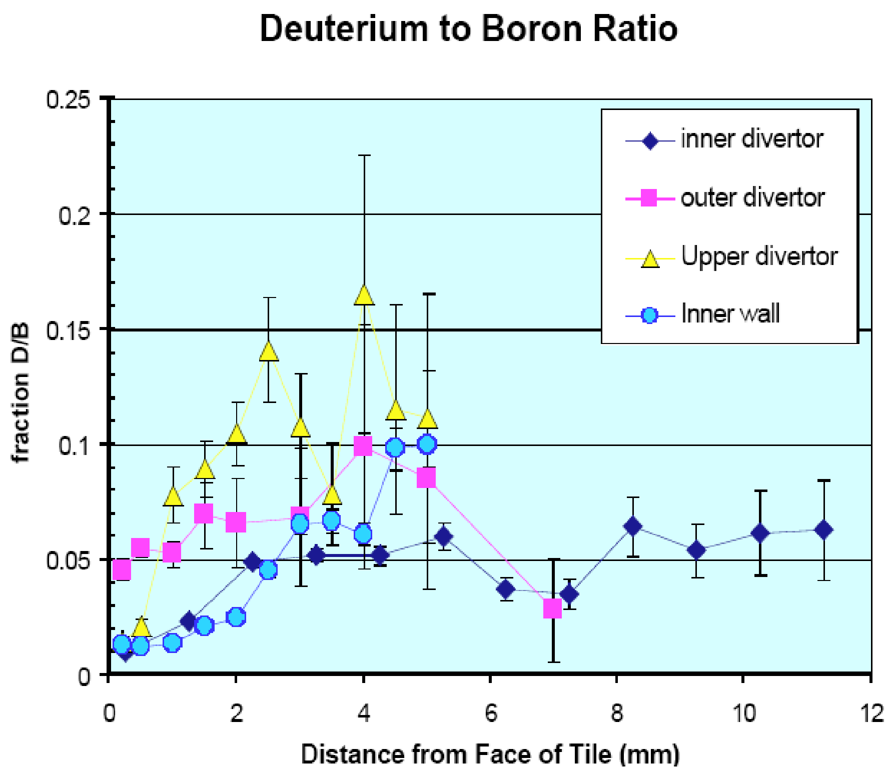




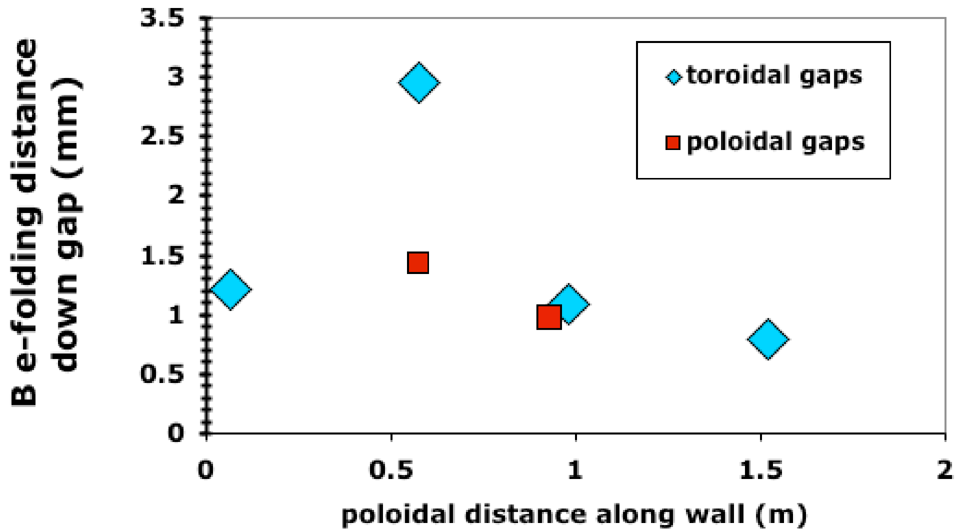
- Role of plasma exposure?

Deuterium/Boron generally increases down gap.

Most deposits very close to surface: $\lambda_{1/e} \sim$ mm

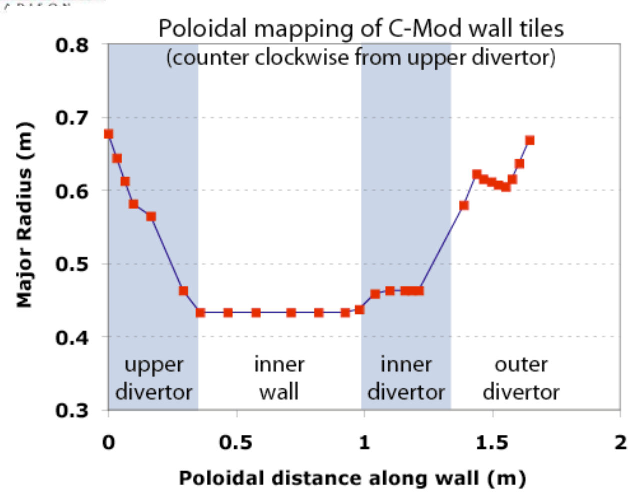


E-folding lengths of film depth into gaps

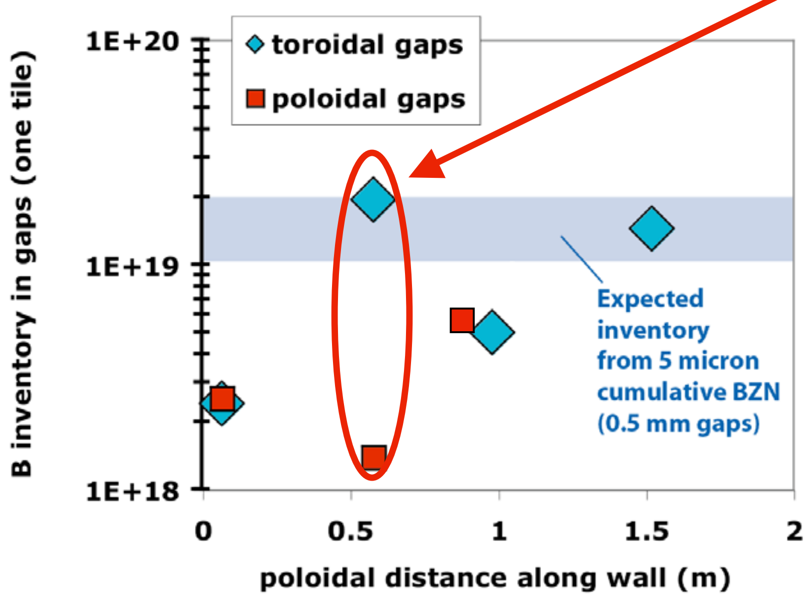


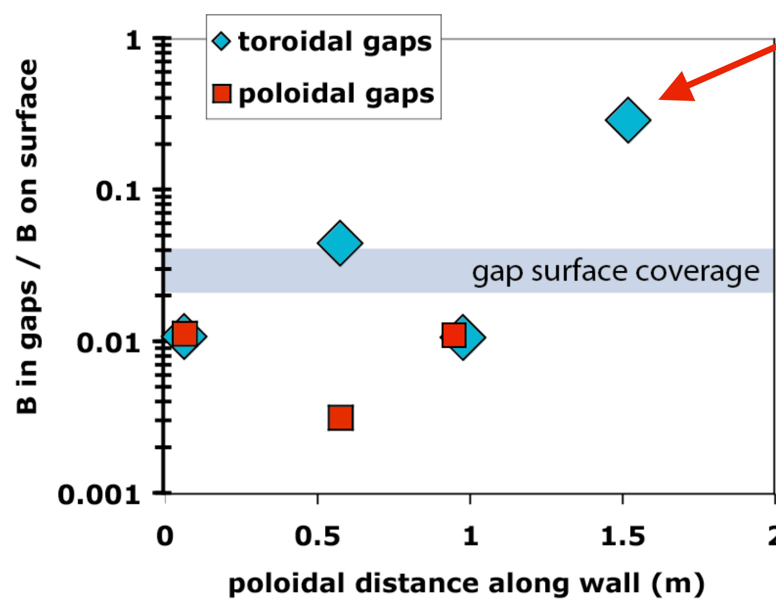
Higher D/B further down the gap => Softer B layer

Boron inventory in gaps generally consistent with deposition during BZN and quasi-uniform neutral deposition through tile gaps.



- Divertor ratios of gap/surface distorted by surface deposition/erosion at inner/outer divertor.
- Again - difference between poloidal and toroidal gap deposition may be due to ionic deposition.



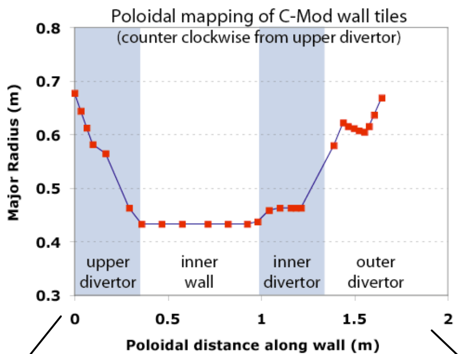


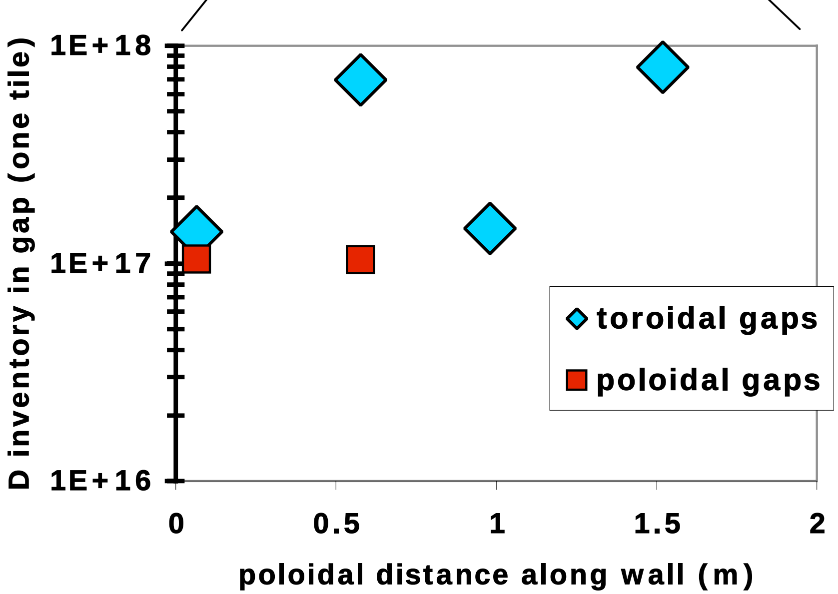
The external source of low-Z boron onto Mo in C-Mod valuable for understanding tile gap deposition processes

- In tile gaps, deuterium codeposition with boron, D/B ~ 2-10%.
  - Real D inventory in gaps probably larger due to isotope exchange.
- Neutral boron flux through gaps caused by diborane molecule dissociation during boronizations plays an important role.
  - Levels of deposition roughly consistent with relative area of gaps in PFCs.
  - Toroidal gap profile suggest ionic deposition at the outer divertor and inner wall.
- As in carbon devices, gaps are a significant location for D retention.
  - Implications for retention in ITER with metals walls + BZN?
- Boron deposits concentrated within top ~ mm of surface
  - Geometrical access for removal by optical techniques (laser, disruption, etc.)?

Deuterium inventory in gaps is not obviously related to plasma fluence.

Gaps hold ~half D retention at outer divertor.





Ratio of D in gaps to surfaces ~1 %, except at outer divertor